# SEMI-ANNUAL REPORT

(for January -- June 1993)

Contract Number NAS5--31363

# OCEAN OBSERVATIONS WITH EOS/MODIS:
## Algorithm Development and Post Launch Studies


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Following the format of my monthly reports, I shall describe developments (if any) in each of the major task categories separately.

1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1993, there are three objectives under this task:

i) Complete and test the performance of the algorithm that was proposed for SeaWiFS and that we believe could form the basis of an atmospheric correction algorithm for MODIS.

ii) Implement the preliminary code so that it can be tested and evaluated through processing SeaWiFS imagery.

iii) Develop a method to correct imagery for the effects of the curvature of the earth. This will be required for imagery obtained at high latitudes.

b. Work Accomplished:

i) The prototype atmospheric correction algorithm that will be implemented for testing on SeaWiFS (Appendix 1) has now been studied through simulations and appears to work well as long as the candidate aerosol models used in the retrieval span the size-refractive index space of possible aerosols. Note, however, that there appears to be a difficulty with highly absorbing aerosols such as those in the Shettle and Fenn (1979) Urban model, and that the present algorithm ignores polarization and stratospheric aerosols.

ii) For the implementation of the algorithm for SeaWiFS processing we generated a set of coarse-grid lookup tables. With the help of Bob Evans and Gene Feldman we have carried out approximately 30,000 simulations (at approximately 1-1.5 hours per simulation) using spare CPU cycles on existing DECstations at RSMAS and GSFC which are dedicated to other projects. This procedure has worked for the coarse-grid set required for development of the SeaWiFS algorithm; however, more aerosol models must be added to the computational set to be assured that the models used for the lookup tables are representative of the range of aerosols likely to be encountered. This set of computations require approximately 2 Gigabytes of memory for storage. Clearly, it is impossible to access these tables directly for the implementation of the algorithm. Thus, a way had to be found to compress even the existing tables. This was accomplished by regression and Fourier transformation as described in Appendix 2. The compressed tables require only 1 Megabyte per aerosol model. We have 16 models, so the tables size was compressed from 2 Gigabytes to 16 Megabytes.

(iii) A large number of computations have been carried out using our spherical shell atmosphere radiative transfer code to examine the influence of the curvature of the earth on atmospheric correction. Analysis of the results have begun. The principal results obtained thus far are:

(a) Surface roughness effects on the correction algorithm computed with the plane parallel atmosphere (PPA) approximation are virtually identical to those computed with the spherical shell atmosphere (SSA). Thus, it appears that the effect of surface roughness on the correction algorithm can be studied using the simpler PPA approximation.

(b) Earth curvature effects on atmospheric correction become important for solar zenith angles greater than about 70 deg., and become very large at zenith angles of 80 deg. However, by computing the Rayleigh contribution to the radiance at the top of the atmosphere using the more-appropriate SSA, the error usually can be reduced significantly. This suggests that for high-latitude imagery, the Rayleigh contribution should be computed using the SSA.

(c) The effect of multiple scattering on the correction algorithm appears to be the same for a PPA and a SSA. Therefore, it appears that modeling focussed on reducing the correction errors attributed to multiple scattering can be carried out using the simpler PPA approximation.

c. Data / Analysis / Interpretation:

i) See Appendix 1.

ii) See Appendix 2.

iii) See discussion above.

d. Anticipated Future Actions:

i) It will be necessary to gain an understanding of why the algorithm fails for an Urban (absorbing) aerosol and find ways to correct it. Also, additional aerosol models must be investigated to understand the limitations of the algorithm. The influence of stratospheric aerosol (volcanic origin) must be assessed as well as the effects of ignoring polarization.

ii) We will continue the SeaWiFS implementation. Test it with CZCS data to eliminate coding errors. This work is being carried out with R. Evans.

iii) We will examine the influence of earth curvature on the newly proposed SeaWiFS algorithm.

e. Problems / Corrective Actions:

i) Even the preliminary set of simulations for constructing the coarse look up tables for SeaWiFS was very computationally intensive. As a result we require considerable CPU power and disk storage. Thus, our Team Member Computer Facilities Plan was revised (Appendix 3) and resubmitted to the Team Leader during this reporting period.

ii) The research version of this code will runs very slowly. It will probably be necessary to find ways to increase the speed.

iii) None.

f. Publications:

i) A paper (Appendix 1) has been accepted for publication in Applied Optics.

ii) None.

iii) A paper describing the results of this work thus far is in preparation and will be submitted to Applied Optics within the next six months.

2. Whitecap Correction Algorithm.

a. Task Objectives:

During CY 1993 we planned to arrange to borrow the required CCD camera from NOAA and obtain some whitecap data at sea from a ship or aircraft. This will allow us to complete our evaluation of the feasibility of using the subject camera to carry out the whitecap study. It is important to note that present MODIS funding does not allow purchase of such a camera until CY 1995, so experimental data can only be obtained when the camera can be borrowed from NOAA coincident with available ship or aircraft time.

b. Work Accomplished:

During the period from June 7 to June 28 a large air-sea interaction experiment (sponsored by Office of Naval Research and Naval Research Lab [NRL] ) took place off the coast of Maryland. This experiment was supported by two oceanographic ships, a blimp, and several aircraft. One of these aircraft, flown by NRL, carried the NOAA Xybion camera system. This turned out to be a very good opportunity to obtain data with which to evaluate the suitability of the Xybion system for studying the whitecap problem. During one week of the operations we monitored the data, during the time available before and after the flights, to check the operation of the camera. At that time the data appeared encouraging.

c. Data / Analysis / Interpretation: None

d. Anticipated Future Actions:

We are making arrangements to receive the camera system, and tapes from the flight. When this occurs we will digitize the camera images and reduce the resulting images. Camera operation will then be evaluated, and if positive this data set will be used to begin our field study of the whitecap problem.

e. Problems / Corrective Actions: None

f. Publications: None.

3. In-water Radiance Distribution Schedule.

a. Task Objectives:

During CY 1993 the objectives are to complete modification of the instrumentation and to start to obtain high-quality radiance data for studying the variation of the water-leaving radiance with sun and viewing angles.

b. Work Accomplished:

Instrument modification is nearly complete.

c. Data / Analysis / Interpretation: None

d. Anticipated Future Actions:

Will deploy the instrument on the next MODIS cruise.

e. Problems / Corrective Actions: None

f. Publications: None.

4. Residual Instrument Polarization.

a. Task Objectives: None

5. Direct Sun Glint Correction.

a. Task Objectives: None

6. Prelaunch Atmospheric Correction Validation Schedule.

a. Task Objectives:

The objectives of this task are two fold. First, we need to demonstrate that our atmospheric correction scheme will work to the required accuracy. To effect this we will apply the algorithm to computing sky radiance in the blue from measurements in the near infrared. We should be able to do this to about the same accuracy as looking downward from space. Second, we need to study the aerosol phase function and its spectral variation in order to verify the applicability of the aerosol models. To effect these requires instrumentation for measuring the sky radiance and the optical thickness of the atmosphere. Such instrumentation is available in our laboratory and is being modified to operate with the relevant MODIS spectral bands. Our near-term objective is to learn how to invert sky radiance to obtain aerosol optical properties, to carry out such inversions, and to study the variation of the phase function with wavelength.

b. Work Accomplished:

Measurements of the sky radiance distribution were performed on a cruise in Monterey Bay during August. Also obtained during this cruise were measurements of the atmospheric optical depth.

c. Data / Analysis / Interpretation:

Sky radiance data has been retrieved from the Monterey measurements in ASCII files in preparation for the inversion.

d. Anticipated Future Actions:

A graduate student will start working this data into the phase function retrieval models.

e. Problems / Corrective Actions: None

f. Publications:

A manuscript ``Retrieval of the Columnar Aerosol Phase Function and Single Scattering Albedo from Sky Radiance over the Ocean: Simulations," by M. Wang and H.R. Gordon, is now in press in Applied Optics. It describes our scheme for inverting sky radiance measurements to obtain aerosol properties.

7. Detached Coccolith Algorithm and Post Launch Studies.

a. Task Objectives: None

8. Post Launch Vicarious Calibration / Initialization.

a. Task Objectives: None

9. Single Scattered Aerosol Radiance and PAR Algorithms.

a. Task Objectives: None

Other Developments

H.R. Gordon participated in the EOS Topical Science Workshop on Aerosols in Greenbelt, MD May 17 and 18, 1993. He presented reviews of the surface reflective properties of the ocean, modeled properties of aerosols over the oceans, the proposed SeaWiFS atmospheric correction algorithm, derivation of aerosol properties over the ocean as a part of atmospheric correction, and an extension of his techniques for estimating aerosol characteristics with MISR.

The PI revised and resubmitted his Team Member Computer Facilities Plan.

The PI and other personnel on the project spent a significant amount time in June in preparing the Algorithm Theoretical Basis Document (ATBD) for the normalized water leaving radiance. This is one of three ATBD'd that we must prepare.

Finally, the third MODIS Semi-Annual report was prepared and submitted.

References

E. P. Shettle and R.W. Fenn, 1979, ``Models for the Aerosols of the Lower Atmosphere and the Effects of Humidity Variations on Their Optical Properties,'' Air Force Geophysics Laboratory, Hanscom AFB, MA, AFGL-TR-79-0214.

APPENDIX 3

TEAM MEMBER COMPUTER FACILITIES PLAN

(REVISION 1)

Contract No. NAS5-31363

OCEAN OBSERVATIONS WITH EOS/MODIS:
Algorithm Development and Post Launch Studies

by

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The proposed research, particularly the atmospheric correction algorithm development, its theoretical validation, and the vicarious calibration/initialization efforts, require direct and inverse solutions to the radiative transfer (RT) equation and are therefore computationally intensive. For example, our highly accurate scalar RT code, which includes scattering by molecules and aerosols, vertical stratification of the atmosphere approximated by two layers (molecules and aerosols in the lower layer, molecules only in the upper layer), and a stochastically rough Fresnel-reflecting air-sea interface, requires about 1.5 hours to run a single simulation on a DECstation 5000/200.

As an estimate of the computational burden, consider the computations that we have recently performed to prepare lookup tables for the atmospheric correction portion of the SeaWiFS processing system --- the prototype of the MODIS atmospheric correction algorithm. These computations consist of all combinations of twelve aerosol models (phase functions), eight aerosol optical thicknesses, thirty-three sun angles, eight wavelengths and a single wind speed (0) for a total of 12 x 8 x 33 x 8 x 1 = 25,344 simulations. When the sea surface is flat, the only case examined at this time, the simulations require 50 minutes on the DECstation 5000/200 for a total computational burden of 2.4 years. We were able to carry these out in about one-tenth this time by borrowing, on a one-time basis, spare CPU cycles on a large number of DECstations. Please note that these computations are short of the those required for the full lookup tables. We estimate that the full lookup tables will require twice as many phase functions, and at least four wind speeds, or approximately eight times the preliminary computation above. Noting that the computations with a rough surface take nearly twice as long to run suggests that it will take an additional thirty-eight years to complete on the existing DECstation 5000/200. Thus the SeaWiFS algorithm when fully implemented will have required about 40 years of DECstation 5000/200 CPU time just to generate the lookup tables. Having these tables on line for research purposes, and for generation of the compressed form of the actual lookup tables to be used in the image processing code, requires a significant amount of mass storage as well. For example, the present SeaWiFS simulation data b base (based on 25,344 runs) requires approximately 1.5 Gigabytes (Gb) of disk storage. The full SeaWiFS set will require about 10 Gb.

In the case of MODIS, the computations must be done in the vector mode (includes polarization) and vector code is 4 times slower than the scalar code (four elements of the Stokes vector are required), so lookup tables with the same resolution will require about 160 years on our existing DECstation.

Note that the above discussion concerns only the generation and storage of the lookup tables, and excludes all of the exploratory research necessary to determine the resolution, proper models, and testing the results. It also excludes all of the other aspects of the research needed to develop and validate the algorithm. For example, the development of an RT code to simulate the overall MODIS system in the visible, i.e., a stratified atmosphere on a spherical earth with waves and whitecaps, to provide a theoretical validation of the algorithms; the significant data processing and mass storage load (digital imagery of the sea surface) required for development of an adequate whitecap algorithm, and the post launch calibration/initialization effort, for which the necessary software must be developed for inverting the sky radiance to provide the aerosol scattering phase function. Furthermore, to test the algorithm operation, and its implementation with SeaWiFS data, will require a computer with at least 100 MB RAM, the expected size of the preliminary lookup tables.

Thus, an extraordinarily heavy computational burden is expected during the entire prelaunch phase of the research. It is clear that significant computational power is required. Our plans are directed toward procuring enough CPU power to insure that the necessary computations can be carried out in a timely manner. We have planned the TMCF with this as the principal goal. Please note, however, that although the approach we have chosen will provide a solution to the problem, the speed with which hardware and software improve may necessitate significant modification to this plan.  Also, we have concentrated on the atmospheric correction aspects of the plan, which will be our focus for 1993 -- 1996. The image processing aspect --- the next five years --- is of necessity less well developed because our needs will in part be determined by the (at present unknown) complexity of the correction algorithm.

We are planning two approaches to this computational burden.

First, we plan to establish our own computing facility that will be centered around DEC Alpha Workstations. Initially, in 1993 we plan to purchase three DEC AXP 3000/400's (Alpha's), each of which should run at about 110 MIPS, i.e., about 4 times the speed of the DECstation. (Note, the DECstation 5000/200's appears to be the only version of the DECstation that is not upgradable to the DEC Alpha.) This will increase our computational computing power by a factor of approximately thirteen. We also plan to solve our immediate disk storage problem by purchasing 3.5 Gb disk drives of each AXP 3000/400. An additional 64 Megabyte (Mb) memory module will be purchased to enable the physical memory of two of the AXP 3000/400's to be increase 64 Mb. In 1994 we shall upgrade the AXP 3000/400's by adding memory and additional disk storage. In 1995 we will purchase a fourth work station to increase our CPU power and we will also procure additional memory and disk storage. We will also procure an Ethernet crossbar to enable efficient communications between the workstations. We believe that by 1996 the equivalent of DEC AXP 3000/400 class work stations will run approximately four times faster than the 1993 -- 1995 versions at a little over twice the cost. Thus, in 1996 we propose to procure three of the improved DEC AXP 3000/400 class work stations in addition to the four we will already have. The three new work stations should provide approximately 1000 MIPS which when added to the 440 MIPS from the earlier models will yield the equivalent of 60 -- 70 DECstation 5000/200's. With improvements in radiative transfer coding, this should be sufficient to generate the lookup tables required before launch as well as meeting the needs of the other aspects of the project. In 1997 and 1998 we will upgrade the Alphas each year with additional memory and mass storage and upgrade our communications to the FDDI/ATM/SONET class. In 1999 we will procure a DEC 4000 AXP class machine to cope with the increased computation burden (image processing) that will occur after launch of the first MODIS, and also to generate the lookup table set for EOS Color. In 2000 we shall upgrade the computers with additional disk storage and processors if possible, and in 2001 we shall purchase a ninth DEC AXP 3000/400 class work station for analysis of the detached coccolith global fields.

Second, we plan to collaborate with Mark Abbott in an attempt to make our codes run efficiently on a Connection Machine at Oregon State University. If this is successful, a significant increase in our ability to explore the parameter space of the atmospheric correction algorithm will be possible, and will enable the development of a more accurate algorithm. For this to be successful, it is necessary to establish a T3 link between Miami and OSU. Such a link is developed in the plans of other MODIS investigators (Abbott and Evans).

Overall, our strategy is the following. We will structure the atmospheric correction algorithm so that its complexity in terms of the size of the lookup tables is flexible. For example, if our computational facilities are only sufficient to compute lookup tables similar to the preliminary tables being prepared for SeaWiFS, we shall design the correction algorithm to utilize tables of this size. However, the larger the tables the more accurate the results will be, e.g., in any interpolation, the more dense the number of points used for interpolation, the more accurate it will be. Thus, the accuracy of the final product will depend directly on the available computational resources.

Maintenance is handled in the following manner. Each computer will be purchased with a one-year warranty and will be placed on maintenance contract after one year. Disk drives are purchased with a five-year warranty and are not placed on maintenance contracts. Other items will be maintained as required.

Major Procurement Events and Approximate Cost

| | Item | CY Total |
|---|---|---|
| 1993 --- 3 DEC AXP 3000/400 | 33,800 | |
| --- 64 Mb Memory DEC AXP 3000/400 | 2,500 | |
| --- 3 3.5 Gb Disk Drives | 9,900 | |
| --- 8 ppm laser printer (PostScript) | 1,700 | |
| | | 47,900 |
| 1994 --- 192 Mb Memory for DEC AXP 3000/400 | 7,500 | |
| --- 3 4.5 Gb Disk Drives | 10,500 | |
| | | 18,000 |
| 1995 --- 1 DEC AXP 3000/400 | 11,300 | |
| --- 2 4.5 Gb Disk Drives | 7,000 | |
| --- 1 Ethernet Crossbar (Kalpana) | 10,000 | |
| --- 8 ppm laser printer (PostScript) | 1,700 | |
| --- Maintenance | 6,000 | |
| | 36,000 | |
| 1996 --- 3 DEC AXP 3000/400 Class Workstations | 72,000 | |
| -- 320 Mb Memory for DEC AXP 3000/400 | 32,000 | |
| --- 6 5 Gb Disk Drives | 17,600 | |
| --- 3 1.5 Gb DAT Drives | 4,500 | |
| --- 1 High quality color laser printer | 10,000 | |
| --- Maintenance | 8,000 | |
| | | 144,100 |
| 1997 --- Communications/memory upgrade, mass storage | 45,100 | |
| --- Maintenance | 15,200 | |
| | | 60,300 |
| 1998 --- Communications/memory upgrade, mass storage | 47,100 | |
| --- Maintenance | | 15,200 |
| | | 62,300 |
| 1999 --- 1 DEC AXP 4000/620 Class Computer with at least 2 processors and high speed IO | 155,000 | |
| --- Maintenance | 15,200 | |
| | | 170,200 |
| 2000 --- Upgrade | 50,000 | |
| --- Maintenance | 30,700 | |
| | | 80,700 |
| 2001 --- Upgrade and 1 DEC AXP 3000/400 Class Wksn | 75,000 | |
| --- Maintenance | 30,700 | |
| | | 105,700 |